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THE SPRUCE BUDWORM EPIDEMIC ON LODGEPOLE IN WYOMING

By
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Forest Insect Field Station,
Coeur d'Alene, Idaho,
April 5, 1930.

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R. W. BALCH

INTRODUCTION

The spruce budworm, in spite of its name, feeds and prospers on many conifers, some of which it injures more severely than spruce. In the Northeast, where it has done the greatest damage, it shows a distinct preference for balsam fir. This is doubtless due to the fact that the caterpillars find suitable food throughout their whole period of development on the fir and when the new foliage has been eaten, feed easily on the old needles. On spruce they are confined to the new growth. Thus, although a great deal of spruce has been killed by this insect, in this region the greatest damage has been done where balsam was most prominent in the stand.

The budworm was first studied intensively in Eastern Canada and although it was known that it would feed on other conifers—hemlock, larch, pine—it was not thought to be capable of becoming epidemic, except in spruce and balsam stands. A few years ago, however, an epidemic appeared on pine (chiefly Pinus banksiana) in the Lake States. Here, although fir and spruce were present, the insect—found to be the same species morphologically—preferred the pine.

In the West the budworm has been known for some time as a serious enemy of Douglas fir, defoliating and killing large areas. In many districts grand fir also has been heavily attacked. But until recently pine, larch, hemlock, etc., had not produced an epidemic and were but little infected except when surrounded by fir. During 1925, however,

a considerable infestation was discovered in a pure stand of lodgepole pine around the southwest corner of Yellowstone Park.

The preferred host here is definitely lodgepole pine. Although Douglas and alpine firs are scattered throughout the lodgepole, frequently surrounded by pines which have had all their new foliage destroyed, the budworm feeds on them only in small numbers. In fact, a closely allied moth, Peronea variana, has done more damage to the fir and spruce in this district than has the budworm.

This is particularly interesting since in Cody Canyon, not 60 miles distant, a large area of Douglas fir is being killed by a race of the budworm which consistently avoids the lodgepole in its midst, as long as it can obtain fir. Two distinct biological races seem to have appeared, quite close to each other, with host preferences adapted to the type of stand in which they exist. Superficially they are the same in appearance, though the insects which feed on lodgepole are invariably smaller. The latter have been named by Busck: Cacoecia fumiferana var lambertiana.

While in nature these races, or varieties, do not appear to change their food preferences readily, they can be forced in the laboratory to change from pine to fir in the last two larval stages, and will complete their development. It may be that when obliged to accept a new host for a number of generations the insect acquires a preference for that host. If that is so there is the possibility of future outbreaks on other conifers.

One important difference between the work of the insect on fir and on pine is that when feeding on pine it confines itself to the

new needles. Not only does it keep to the new foliage, but it feeds almost entirely at or near the base of the needles, making a hole through the bundle sheath to reach this part. This seems to be due to a preference for tissue which is growing. Even the later stages avoid the mature tissue. The epidermis may be too tough or the mesophyll unpalatable.

On fir the whole of the leaf is readily eaten, although the younger stages need young tissue. Not only is old and new foliage consumed but young twigs are attacked. As a result fir is more rapidly killed. On pine the damage to the tree is less, for the old foliage is undestroyed, and on normal trees it will take three or more years of concentrated attack to effect complete defoliation.

In the lodgepole area little mortality has occurred until after the third year of attack and this is greatest in the dense, younger second growth. Probably more than three years infestation are necessary to kill thrifty trees although leaders are often killed the first year. The area infested in 1929 covered some 75 square miles. If the epidemic continues there will be considerable loss of timber. (Figs. 7 and 8).

Parasites are becoming numerous and the outbreak may be controlled by natural means in the near future. However, that is pure speculation. Artificial control is difficult. It is being attempted in Canada by arsenical dust applied from aeroplanes. The habit which the caterpillars have of spinning webs of silk around the foliage upon which they feed makes poisoning rather difficult on fir. On pine, however, it is more difficult still, since the feeding is all done at the bases of the needles, which are particularly hard to reach with the poison. (Fig. 3).

DESCRIPTION OF INSECT

Cacoecia fumiferana as it is generally found in Eastern Canada, where it feeds on spruce and fir, has been described in all its stages by Gibson (1925)* The specimens collected from Douglas fir at Bechler River correspond closely to this description, except for some color variations in the adults. It has not been carefully studied.

The variety, or subspecies, on lodgepole, however, is distinctly smaller and has differences of colour in larva and adult.

The Egg. Oval, flat below, convex above. Pale green with a transparent shell which forms a colourless margin around the egg. This shell slightly reticulated. The eggs are almost invariably laid in two rows on the flat side of the lodgepole needle. They overlap, shingle-like, leaving about half the egg uncovered and one single egg is generally placed in the centre at the end of each mass, giving the mass an even number. As the embryo develops the egg turns yellow, then the head of the larva begins to show black. Emergence takes place at the uncovered point leaving the shells empty and transparent. Parasitised eggs have the amnion black and stand out distinctly.

The egg masses varied from 4 to 62 in number with an average of 20.

* Gibson, A. 1925 Observations on the Spruce Budworm
Trans. Roy. Soc. of Canada. Vol. XIX. Sec. 5

First Instar. Head capsule, dark brown, 23 M.M. wide, mouthparts and setae pale. Body, pale yellowish green with a pale brown prothoracic shield, setae slender, pale.

Second Instar. Head almost black, 29 M.M. wide, body pale yellow with prothoracic shield brown. Tubercles more distinct, legs somewhat dark. This instar is shorter and broader than the first. First moult takes place within hibernacula.

Third Instar. Head dark brown, 40 M.M. wide. Body somewhat darker.

Fourth Instar. Head 52 M.M. wide; body varies between brownish greyish and pink on yellow ground.

Fifth Instar. Head dark brown; 75 M.M. Prothoracic shield dark brown. Body greyish brown suffused more or less strongly with red. Tubercles whitish-yellow.

Sixth Instar. Head 1.0 M.M. wide, light brown, prothoracic shield sometimes light but generally dark brown. (All larvae collected at Westree, Ontario had the head darker than the shield, as in Gibson's description.) Body 18 M.M. long, as compared with an average of 22 M.M. for the Westree larvae, red to reddish brown, or occasionally brown with a pink suffusion. Tubercles prominent, whitish.

Pupa Length: male 8-9 M.Ms, female 8-10 M.Ms. Brown, somewhat reddish. Two rows of short spines dorsally across abdominal

segment except I -- reduced considerably on II, III, VIII, and IX. Cephalic row large. Cremaster with 8 hooks. Distinction between sexes shown in Fig. 2. See also Fig. 1.

Gibson gives lengths of 11-13 MM and 12-16 MM. Fifty pupae from Douglas fir at Cody Canyon had an exactly similar range. Twenty-four pupae from Douglas fir at Bechler measured 10--12 MM for males, 11--14, for females.

Adult. The moths have a wing expanse of 18-20 MM, the males with longer wings, but smaller abdomens. The colour of the head, abdomen and forewings dorsally is brown ochre with pale straw-coloured markings and fringe. The eyes are blackish, streaked with white. The underwings and whole ventral side are pale straw colour except for some brown scales on the abdomen and first two pairs of legs. The markings vary but there is generally a pale transverse band near the apical margin.

LIFE HISTORY AND HABITS

The eggs as described above, are laid during the last week of July and the first week or so in August. (The dates given in this description are for the neighbourhood of Bechler Ranger Station, and will vary for other regions according to altitude and latitude. It was found also that there was about a week's difference between the dates of development on the flat and on a slope facing south. All stages are earlier on southern slopes, corresponding to the earlier

development of the host.) The egg masses are lighter in colour than the pine needles, but not very conspicuous. They may be found anywhere in the crown but most of them are in the upper half.

The period of incubation has not been accurately worked out owing to absence from the area, but it is between 6 and 10 days. By August 17 most of the eggs had hatched but some were found which did not hatch until August 22nd.

On hatching the very small larvae do a good deal of travelling and those observed in the laboratory seemed to be on the move for the better part of two days. They tend to go upwards and probably become more or less concentrated near the top of the crown. When disturbed they drop by means of a silk thread. In fact they often leave a thread behind as they travel and when climbing the side of a glass container can be seen to weave a zig zag form of ladder up which they climb. If they do not reach a lower limb when dropping on a silk thread they almost immediately commence to crawl back up the thread which they gather between the prothoracic legs, pulling themselves up with the mouth. These habits are common to all the larval stages.

In spite of this apparent restlessness it is doubtful if in the field the larvae get far from the egg mass. They seem to select a place for hibernation near where they hatched. Any place of concealment will serve the purpose but most of them seem to get under the old scales or at the bases of the needles between the woody base and the twig. Quite a few crawl into the empty needle sheaths from which the needles have fallen after being chewed off by the previous generation. None were

found on the bark away from the needles. They build a cocoon or hibernaculum of white silk by lining the sides of their crevice and spinning a quite heavy covering. Sometimes these are gathered together and built on top of each other. Although they are easily seen when you know they are there the hibernacula are difficult to find in the field.

The first moult takes place in the hibernaculum shortly after it is completed and the 2nd instar assumes a somewhat curled up position in which it spends the winter.

Observations of the early larval stages are lacking but the second stage doubtless emerges from its cocoon about the time the buds of its host begin to break. Some feeding seems to be done on the bursting buds which deforms, or kills them. This occurs in the tip of the crown chiefly, where feeding is concentrated at the beginning of the season, and as a result the leaders are frequently destroyed -- almost invariably on a heavily infested tree, (Figs. 6). Feeding probably starts around the first of June.

As the needles emerge from the bundle sheath the tips become hardened. The only part which can be eaten by the budworm is that near the base, generally within the sheath, where the tissue is less mature. Holes are bored through the sheath and the needles are generally chewed through at this point, although most of them remain within the sheath, held there partly by the webbing of the larvae. They do not turn brown for some time and it is not until about the first of August that the work becomes conspicuous at a

distance. A great many of the needles remain attached to the twig till winter. (Fig. 4). Sometimes a chewed-off needle continues to grow and later in the season looks as if it had been fed on from the tip. (Fig. 1).

The larvae spin a web among the needles binding them together and forming some kind of protection before feeding commences. This adds to the difficulty of reaching the feeding point with poison. When the needles of one shoot have been eaten out at the base the larva migrates to another shoot. Rapidly growing shoots will easily feed one larva without migration. Two or three larvae often occur in one shoot, but generally only one in the later stages. The larvae spread from the top downwards.

Not much migration from tree to tree was observed. The caterpillars were frequently found hanging from threads, particularly when the sun was warm, but almost always they crawled back up the thread or got on to another limb. Only a very few larvae were found on the mats of cotton which were placed beneath three of the trees, although one of these mats was observed two or three times a day. However there must be a certain amount of falling from high trees on to lower trees, and possibly in heavily inf ested areas some actual migration from tree to tree.

There is a good deal of variation in the rate of development. As many as four different instars have been found on the same day. Collections were made by nipping infested shoots from a number of trees at random. The results are given in the following table.

Date	Stages Collected						
	Larval Instars						
July	3rd.	4th.	5th.	6th.	Prepupal	Pupae	Adults
10	2	6	25	1	-	-	----
11	-	12	35	56	-	-	----
12	2	18	22	66	1	-	----
13	1	6	16	46	-	1	----
15	-	2	18	48	4	-	----
18	-	5	25	67	7	15	----
21	-	-	11	55	9	27	----
24	-	1	8	26	8	34	First noticed
28	-	-	2	41	15	76	
29	-	-	2	10	14	67	Several
30	-	-	3	9	10	71	
Aug 1	-	-	-	7	12	70	Common
"2	-	-	1	5	10	58	Abundant

Before pupation the larva spins a thin loose web or cocoon around itself among the dead needles upon which it has been feeding. It then becomes quiescent, passes through the prepupal stage, and in about a day transforms to a pupa. The pupa gradually becomes darker and the adult emerges in from 6 to 10 days. As the time for emergence approaches the pupa becomes very active and wriggles out of its web, aided by the dorsal spines on the abdomen but held to the web by the hooks of the cremaster.

The adult can be seen through the pupal case working its body forward by peristaltic movements of the abdomen, forcing the head against the fore part of the case until it splits in the centre back to the meso thorax and along the sides of the legs and antennae in front. The moth crawls from the case and suspends itself by the legs. In 4 or 5 minutes the wings have fully expanded and seem fairly rigid.

Oviposition was observed in the laboratory on the day following emergence. However, although fifty females were placed in jars with the same number of males and the abdomens of the females were extended and green with fully formed eggs, only three of them laid eggs and the remainder died in a week or ten days. It is not known whether this was due entirely to unnatural conditions of captivity and other work prevented investigation of this in the field.

During the first week of August there was a large flight of moths. They were attracted in large numbers by a lamp at night.

During the day time they were very numerous resting on the twigs and foliage. On returning to the station August 17th moths were very scarce and many of the eggs had hatched. It was surprisingly difficult to find the eggs or larvae, although several days were largely devoted to the careful examinations of different sized trees at different points. Shells of hatched egg masses are as easy to see as the unhatched eggs, although they are sometimes destroyed by mites. Ten 30 ft. trees averaged 48 eggs per tree. Ten 45 to 50 ft trees averaged 102 per tree, mostly in the top of the crown. Oviposition on smaller reproduction seemed less common than on the upper story.

In the laboratory the males began to emerge before the females. They also died two or three days earlier.

SPRAYING AND DUSTING EXPERIMENTS

Method.

In order to test the possibilities of control by the use of arsenicals some experiments were carried out with a hand sprayer and a hand duster.

The poisons used were from the Niagara Sprayer Co. of Middleport, N. Y.

	Arsenate of Lead	Calcium Arsenate
Active Ingredients	98%	70%
Total Arsenic Oxide	30%	40%
Equivalent of Metallic Oxide	19.5%	26%
Arsenic in Water Sol. form.	.50%	.50%

A Banner sprayer and Root Hand gun were used and it was possible to treat trees as high as 15 ft. Trees about 8 ft. high were more satisfactory as examination before and during the experiment was easier.

It was necessary to use trees sufficiently isolated so that there was no probability of subsequent re-infestation. Migration from tree to tree in the later stages, however, did not seem to be very common. These trees were examined before the application of poison and the degree of infestation measured by the proportion of shoots webbed up. They were examined from day to day to estimate the mortality. Three trees had a cotton mat stretched beneath them

and sewn around the trunk to catch falling larvae. Finally where there seemed any promise of a satisfactory degree of mortality the trees were examined shoot by shoot and the dead and living counted. Single trees and groups were used.

The chief object was to discover if it was at all possible to kill the larvae. The applications were in the main heavy, but lighter applications were tested. The heaviest applications of dust were sufficient to give a distinct grey cast to the foliage. The lightest applications of dust corresponded roughly to the coverage obtained in a mature stand by about 25 lbs per acre. The strengths of spray ran between 4 and 10 lbs of powder to 100 gallons of water. The trees were soaked with the spray.

The dusting and spraying commenced in the early morning of July 12th and continued till July 16th. Applications at different times of the day, from 5 am. to 6.00Pm. were tested to observe the effect of humidity on adhesion.

98 trees were treated. 71 of these were in 8 groups, 27 were single trees. The height of these varied from 5 to 15 feet.

Results.

On none of these trees was there sufficient mortality to warrant any expectation of success from spraying or dusting at this stage of development.

One 14 ft tree, beneath which a cotton mat had been placed, was dusted heavily 5. 00Am. July 12th. It was examined two to three times each day. Only five dead larvae were collected. One of these was being carried down the trunk by a red ant (Formica rufa aggerans ?)

another was being removed from the mat by a black species of ant, and it is probable that dead larvae are often accounted for in this way. However, the final count disclosed 59 pupae as compared with 71 on a check tree of similar size, showing that the maximum possible mortality from poison was probably not more than ten per cent. None of the other trees showed quite as promising results as this. No burning of foliage resulted.

Discussion.

The chief reason for this failure to poison the larvae lies in their habits of feeding. They confine themselves almost exclusively to the tissue at or near the base of the needles. In fact most of the feeding is done through the thin brown sheath which encloses the base. This seems to be the region of maximum growth, where the epidermis is softest and the tissue least mature. It is more "succulent."

Owing to the form of the twigs and the fact that the needles are drawn together by the caterpillars in a web of silk it is very difficult to apply the poison to the point where the feeding is done, especially as a good deal of the feeding is done within the sheath; also the dust and spray do not adhere as well to the new needles as to the old, owing apparently to the smoother surface or to a different surface charge. The spray did not spread so well on the new foliage. Thus by far the greater part of the poison is applied to the foliage which is not fed on.

Another important reason may be the late stage at which the experiments were carried out. On July 12th of 108 larvae collected

at random 66 were in the final instar, 22 in the fifth, 15 in the fourth, and 2 in the third. Not much feeding would be done by the mature larvae. Nor do the later stages feed openly on the needles as may happen on fir. It is possible that the earlier stages are more susceptible to poison and the experiments should be continued, commencing at the time the buds begin to open. However, it will probably be difficult to achieve complete control by arsenicals with the budworm feeding on lodgepole. The shape of the needles exposes a small surface to the dust compared with fir or broadleaved trees; only a small area of this on the new needles is touched by the larvae; adhesion to this part is difficult to obtain; and in addition it is protected, in the last three stages at least, by a web.

Laboratory Experiments

In order to test the efficacy of the poison when not hindered by the conditions mentioned above three small experiments were conducted in the laboratory.

July 15 new lodgepole foliage untouched by the budworm was thoroughly sprayed with calcium arsenate (7 lbs to 100 gals) and placed in mason jars with ten larvae of the fifth instar. The experiment was duplicated with larvae on Douglas fir. Ten similar larvae were placed on lodgepole foliage unsprayed. July 17 three of the first lot were dead and four of the Douglas fir lot. July 18 two more of the Douglas fir lot and one of the check lot were dead. The remainder pupated.

These experiments, owing to lack of time to collect more fifth stage larvae were too small to be of much value but they indicate

the difficulty of poisoning this stage, particularly on lodgepole, even when the protection of the web is removed.

July 20 six larvae of a pine sawfly (Hopk. U. S. 18665) feeding on the old foliage of lodgepole were placed on fresh foliage heavily dusted with calcium arsenate. They were all dead in about a day and a half. Larvae feeding openly on the old foliage would be easily poisoned.

Aeroplane Dusting

If it were proved possible to poison the larvae with calcium arsenate dust, the dust could be applied by aeroplane. Such an area as Hechler R iver would offer fairly satisfactory opportunities for aeroplane work, owing to its comparative flatness and to a number of open spaces which might be used for landing.

But the expense and difficulties of aeroplane dusting of forests are considerable and it is as yet only in the experimental stage. The writer took part in some aeroplane dusting for budworm by the Canadian government in June 1929 at Westree, Ont. They are working out some of the technical details of application and have made considerable progress, although the cost is high. This is borne by the Air Board, the Forestry Branch, and the Entomological Branch in cooperation. Successful control of the hemlock looper has been achieved but results with the spruce budworm have been less convincing.

The plane used was a Ford Trimotor adapted with a "hopper" to carry 1600 lbs of dust and converted into a seaplane. This seemed more satisfactory than smaller types. Necessary improvements of the hopper, which was originally designed for cotton dusting, to ob-

tain heavier and more uniform discharge are being worked on this winter.

Apart from the question of the most satisfactory equipment the following points must be borne in mind.

1. The training of the Pilot: In order to be able to apply the desired poundage per acre and apply it uniformly the pilot needs a good deal of experience in the work. It should be possible eventually for a trained man, given a map and necessary instructions, to make the application with little assistance from the ground.

2. The Nature of the Country: Hilly country is very difficult to dust. A good landing ground is needed, not too far from the forest to be dusted, and not too far from the road or railroad over which the gas, dust, and supplies are brought. Lake country is much better than mountain country.

3. Weather and Air Currents: The period during which the larvae can be successfully poisoned may be a short one, perhaps not much more than a week. If suitable dusting weather does not occur the opportunity is lost for the year. Rain and wind prevent dusting and remove the dust from the foliage after dusting. While an experienced pilot may be able to dust in a 5 mile wind, a calm is needed for good results. Also a certain degree of moisture on the foliage is necessary to obtain satisfactory adhesion. At Westree it was found that during most of the day rising air currents from the forest prevented the dust cloud settling. The only time when conditions were satisfactory was during two hours

or so following daybreak .

4. The amount of Dust: There is a great deal of surface to be covered in a mature forest. If the infested species are mixed with others a good deal of dust is applied ineffectually to the uninfested species. The ground cover receives a lot and some is blown off the area. Results at Westree seemed to indicate that 40 lbs per acre might be needed to receive results in a mature fir stand.

5. Effect on other Animals: There is the possibility of poisoning browsing animals. This danger would be important in some areas and needs investigating, although it does not seem to be generally serious.

6. The Cost: Dusting forest lands is practiced commercially in Germany. But under the more extensive forestry conditions in America the cost would often be too large in relation to the value of the timber -- unless it were possible to control an incipient epidemic by a small operation. At any rate the efficiency of the poison against the particular insect doing the damage should be carefully worked out before aeroplanes are experimented with.

NATURAL CONTROL

In the heavily infested stands where defoliation was nearly complete there were signs that the numbers of the insect had been reduced by a shortage of food. With each year of attack the insect at first increases in numbers, at the same time the annual growth of needles decreases until it is not sufficient to support the insect population. Thus the number of moths emerging this year from stands infested since 1926 was smaller than in the areas infested a year or so later.

Meanwhile parasites increase in numbers. In 1928 a number of Tachinid, Chalcid, and Ichneumon parasites were reared from the budworm. The most important were two Ichneumons (Hopk U.S. 18664 and 18666) which attacked the larvae and emerged from the pupal stage. T wo small trees near the Fall R. were caged with cheese cloth July 15th and 197 larvae placed on them. The parasites were collected every other day while in the area and the numbers checked by examination of the pupal cases. The final count showed that 117 moths and 55 parasites emerged while 25 pupae or larvae died.

Parasitism of pupal cases collected and reared in the laboratory was in the neighbourhood of 30%.

The following Tachinids were reared but were less important:

Nemorilla floralis Fall. (18686)
Madremyia saundersii Mall. (18687)
Actia pilipennis Fall. (18685)

Parasitism of the eggs by Trichogramma minuta Riley was important. Nearly 20 per cent of the eggs collected were parasitized by this cosmopolitan little chalcid. Parasitized eggs are easily recognized by the amnion turning black. The number of parasites to an egg varied from one to five. They emerged about the same time as the budworm larvae hatched, or a few days later.

Further notes on parasites are awaiting determinations.

POPULATION COUNTS

In a study of an epidemic, particularly when control measures are contemplated, some method of estimating the status of the epidemic and determining its future development is extremely desirable. It is also very difficult to arrive at.

However, it would be possible to make counts of tree "population" and use these as an index of the probable point on the curve which the epidemic had reached. Such counts would show the degree of defoliation, the number of budworm adults per tree (per acre), and the number of parasites. To interpret them accurately, however, would call for a good deal of experience with such work.

The only period at which such counts could be made with the budworm is during pupation. At this time the insect is stationary on the tree. It is also possible to obtain the percentage of larval and pupal parasitism with some accuracy.

In order to get an idea of conditions obtaining in the trees at certain points in the infestation, and in the hope that this would give valuable points of comparison with conditions the following season, a number of counts were commenced. Representative trees in the oldest infested area of young growth near the Fall River were chosen. These were cut and counts made from the top down, whorl by whorl. Owing to the small size of the trees it was possible to let them down gently without jarring the branches. If large trees were being studied they would have to be delimbed over a mat of cotton. The crown was divided into three parts to give an idea of conditions at different levels. Although the work was interrupted at the start and only seven trees were counted, results are given below for what they are worth.

Tree	Height (Ft.)	Length of Crown (Ft.)	First Infested	Number of Whorls	Shoots		Pupae			Larvae				Date
					Attacked	Unattacked	Living	Emerged	Dead	Living	Dead	Parasites	Predator ?	
I	17	15	1927	1-8	221	--	23	15	--	4	--	13	-	July 30
				9-14	279	2	52	9	3	6	1	11	1	
				15-19	154	56	13	--	--	1	--	1	-	
II	20	18	1927	1-6	141	8	9	7	--	1	1	5	1	July 31
				7-11	120	68	15	3	--	5	1	9	--	
				12-17	64	100	3	1	--	2	--	5	--	
III	30	26	1927	1-11	590	--	6	--	1	--	--	9	1	July 31
				12-18	644	--	33	7	1	1	1	21	8	
				19-25	270	34	20	2	--	1	--	4	1	
IV	23	17	1927	1-8	143	51	5	2	--	1	2	5	--	August 1
				9-14	220	135	18	1	1	--	6	10	1	
				15-20	50	51	6	--	--	--	--	--	--	
V	24	9	1926	1-6	61	--	--	--	--	--	--	1	--	August 1
				7-10	76	10	--	1	--	--	--	4	--	
				11-14	68	12	1	--	--	--	1	--	--	
VI	35	21	1927	1-6	44	--	--	--	--	--	--	--	--	August 1
				7-12	180	58	8	2	1	--	1	1	1	
				13-17	114	30	4	--	--	--	--	--	--	
VII	25	20	1927	1-7	210	--	20	16	1	2	--	14	1	August 2
				8-14	290	10	56	10	2	4	2	11	2	
				15-22	189	50	14	2	1	--	--	3	--	
					4028	675	306	78	11	28	16	127	17	

The following points are brought out by these figures:

1. On these trees, heavily infested for the third season, 14 per cent of the current year's shoots were unattacked. The undamaged growth, however, was almost all in the lower part of the crown and consisted of shoots which were generally somewhat shaded and less vigorous, and of less importance to the tree than those attacked.

2. There is considerable variation between neighboring trees in the degree of damage. In general the most severely damaged had the smallest population owing to migration or starvation.

3. Twenty-two per cent of the total number of mature larvae had been parasitized -- mostly by the ichneumons, some by the tachinids previously mentioned.

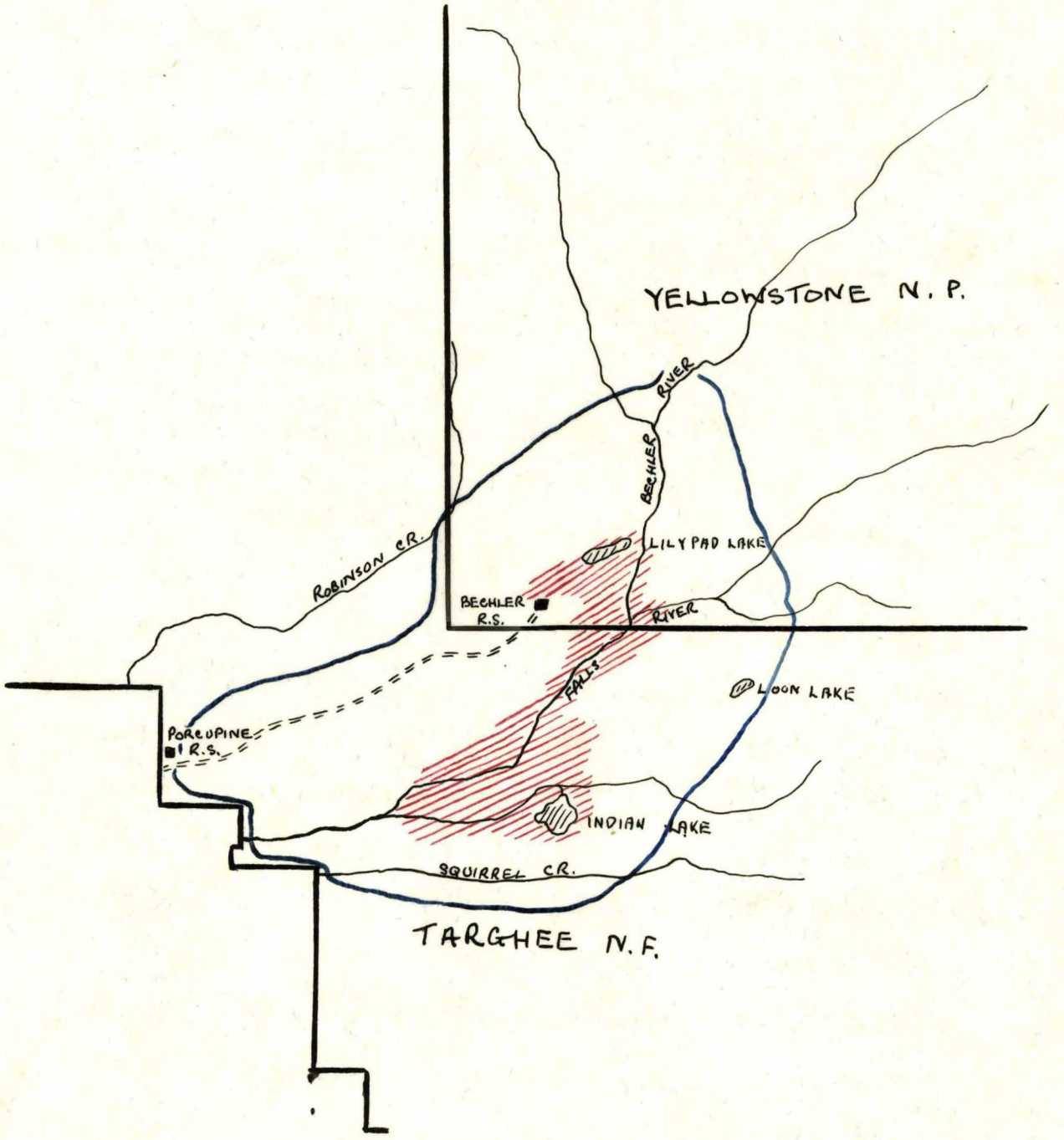
4. Six per cent of the mature larvae and pupae were destroyed by some other agency -- apparently disease. Nearly four per cent of the pupae had been destroyed, apparently by some predacious insect. Some of these are chargeable to a pentatomid -- awaiting determination.

THE INFESTED AREA

An exact survey of the area has not been made but trails have been ridden and notes taken of the infestation at a number of points. The limits of the area are less accurately known in the Targhee National Forest than the Yellowstone Park, but the extent of the area known to be infested in 1929 is shown on the map (Fig.p.26).

Owing to the fact that the budworm feeds only on the current year's growth of needles it is possible to date fairly accurately the year of first attack. Defoliation by the insect three and four years ago can be recognized by the occurrence of needles which, after having been chewed off at the base, have grown out and remain as stubs, a third or less of their natural length. Defoliation from other causes, as for instance the premature shedding of foliage in the fall, leaves no such stubs.

In this way it was determined that the outbreak commenced in 1926. Feeding in that year was very slight. The epidemic first caused noticeable loss of foliage in 1927 and parts of the forest, particularly in the neighborhood of the Falls River, lost 25 to 75 per cent of their new foliage. The shaded area on the map corresponds roughly to the area attacked in 1927. In 1928 the infestation spread considerably and in 1929 it involved the area surrounded by the blue line -- over 75 square miles. During the last two years the loss of new growth in the heavily infested area has ranged from 50 to 100 per cent.



— KNOWN INFESTED AREA

/// AREA OF HEAVIEST DEFOLIATION.

SCALE: 4 MI = 1 INCH.

INJURY TO STAND

The greatest damage has been done to the young second growth. Defoliation is almost complete in many of the dense stands which came in after fires thirty, forty, and sixty years ago.(Fig.8) The mature stands, generally considerably thinned out by fire, have been less severely attacked. It seems that dense stands, not too high, offer more favourable breeding and feeding conditions. Possibly they offer more protection from the wind and the moths naturally collect there. T here is also the fact, to be borne in mind, that the degree of defoliation as estimated by the eye depends on the number of years' growth, previous to the attack, which persist on the trees.

The whole question of damage, apparent and real, to the physiological system of a tree by a defoliator which kills only the current growth, is tied up with the persistence of the old foliage. There is great variation between individuals on the same site. One tree will have six years' growth of needles, another three or less. While a sickly tree will rapidly lose its old foliage, "vigour" does not always seem associated with its persistence. Older trees, putting on comparatively smaller amounts of new foliage, will often be found to carry six years growth, while young rapidly growing trees may have but three. If the loss of foliage is governed to a considerable extent by light, as seems likely, then the production of large amounts of new growth would rapidly shade out the old needles and vice versa.

Thus loss of foliage would be automatically controlled by the need for foliage. Similarly dense stands would lose foliage more rapidly--from lack of light.

This is a rather complex problem in plant physiology but its solution would help to determine the type of stand which would suffer least from this kind of defoliation. It is important also to determine the value of the old foliage to the tree. To what extent will this "reserve" of leaves compensate for the loss of two or three years growth?

Four permanent sample plots were established in the Bechler area to follow the effects on the stand for a number of years. The size, crown class, degree of feeding and condition of foliage were noted for each tree. Each tree was classed according to its foliage as 'Brown,' 'Green', or 'Intermediate.' The first class included the dying trees on which the little remaining foliage was browning. The 'Green' class included those with still a good deal of old foliage and quite green. They showed no signs of being killed by defoliation. The intermediate class had scanty foliage, some of which was brown, but the greater part of it green. They showed no immediate signs of dying.

Two tenth-acre plots taken in even-aged dense stands which had been quite heavily infested for three years are tabulated below according to foliage and crown classes. The dead trees, which were fairly numerous have been omitted from these figures as they were almost all seriously suppressed or injured trees which were not destined to survive in any case.

Plot I

33 years old 25 to 35 feet high 2" - 6" DBH 1570 trees per acre

	Overtopped	Intermediate	Codominant	Dominant	Total
Brown	8	7	2	--	17
Intermediate	4	14	12	--	30
Green	11	45	40	6	102

Plot II

60 years old 50 to 60 feet high 4" to 8" DBH 1270 trees per acre

	Overtopped	Intermediate	Codominant	Dominant	Total
Brown	8	5	--	--	13
Intermediate	4	5	5	1	15
Green	7	27	45	8	87

These plots represent the average conditions in the heavily infested second growth. A process of thinning from below has commenced, if such a phrase can be used of these even-aged stands. The larger trees are not in immediate danger of death, although a good many of them have been almost completely defoliated and may die. Continuation of the epidemic in its present severity would probably kill the majority of the trees in the next two years.

Most of the trees on these plots have had their leaders and many of the buds and twigs in the upper part of the crown killed.

The other plots are in more recently infested stands and show no signs of mortality.

INCREMENT STUDY

Cores were taken from a number of trees in the area which had been infested since 1926. Examination of the foliage showed that some slight feeding had occurred in 1926, on a few trees. In 1927 the feeding was more general and involved 25-50% of the new foliage. In 1928 and 1929 the greater part of the new needles was destroyed, over 75%.

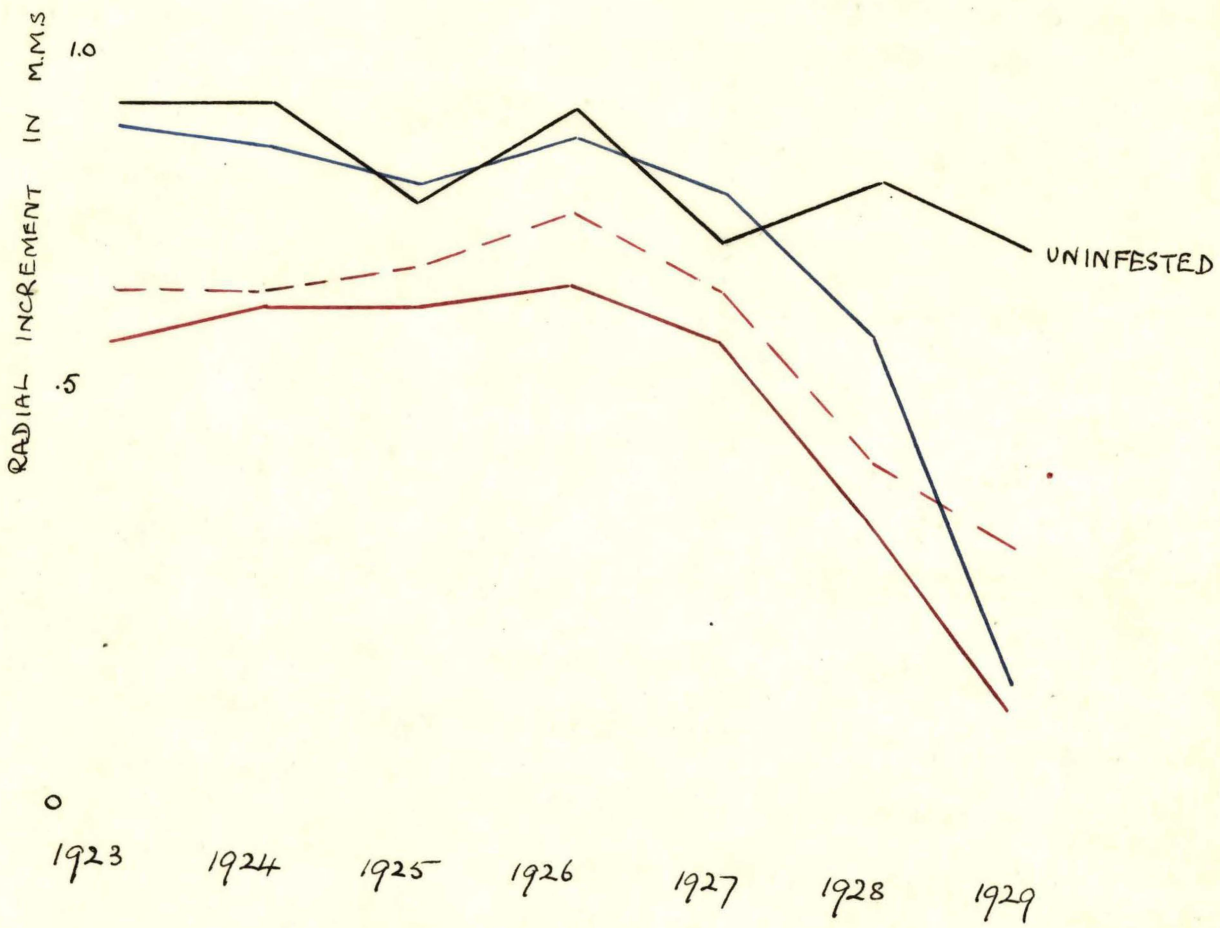
There were, however, scattered through the stand, a number of trees which had been but lightly attacked. While the majority of the trees had very thin crowns and a good many brown needles, these others were green and had lost comparatively little foliage, although they were by no means free from attack. Borings from these trees were kept separate.

Stands of two ages were studied, both dense even-aged stands of fire origin. One was 35 years old, of the type which shows most evident damage from the epidemic, the other 60 yrs. old with the destruction of foliage not quite so evident.

As a check a number of cores were taken from a 40 yr. old stand outside the infested area but immediately bordering it. These cores were collected during the first of September and there can have been but little growth after that time which would appreciably affect the results. Examination with the microscope showed that summer wood formation was well advanced if not completed.

Measurements were made of the annual increment from 1923 to 1929.

EFFECT OF DEFOLIATION ON INCREMENT AT D.B.H.



Trees suffering from any abnormal condition influencing growth were not used, and no suppressed trees were used--all were co-dominant. The totals for each year were brought to an average. There was sufficient uniformity among the trees to permit this method of figuring the average increment for the stand.

AVERAGE ANNUAL INCREMENT OF RADIUS IN MILLIMETERS

Year	No. of trees	1923	1924	1925	1926	1927	1928	1929
Uninfested plot:	57	.93	.94	.81	.94	.77	.86	.78
35 yr old plot; trees heavily attacked	145	.90	.88	.84	.90	.84	.67	.21
60 yr.old plot; trees heavily attacked	88	.61	.66	.67	.70	.64	.42	.14
60 yr.old plot; trees lightly attacked	29	.68	.68	.72	.80	.70	.49	.38

See Graph. (Fig).

This shows that the increment at D.B.H. was not affected until 1928 but it dropped rapidly in the second and third years of attack. Under the conditions of feeding on lodgepole there was apparently no noticeable increase in basal increment during the first year, as found by Craighead in the case of balsam fir, but it may be seen that the infested trees do show a smaller decrease in 1927

than the uninfested trees. Study of the relation between increment at the top and the base was not carried far enough for any conclusions.

The trees that were less heavily attacked will be seen to have been growing somewhat more rapidly than those in the same stand which were attacked. These figures, however, are but indications of possibilities, to be studied more thoroughly.

The decrease in annual increment is also reflected in the length of the shoots. (Fig.5)

Acknowledgment

The photographs in this report were taken by H. J. Rust with the exception of Figs. 7 and 8 which were taken by the author.

Fig. 1. Twigs of lodgepole infested with Cacoecia fumiferana var lambertiana(?). Pupal cases attached to webs by cremaster after emergence of moths and parasites. Note the evidence of feeding and that needles have grown out since fed on.

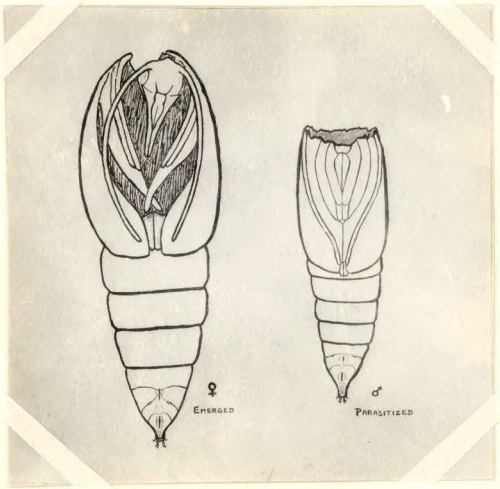


Fig. 2. (1) Pupal case of female of spruce budworm from which moth has emerged. (2) Pupal case of male of spruce budworm from which ichneumon parasite has emerged.

Fig. 3. Lodgepole after one year's feeding by spruce budworm. Most of the webbing and dead needles have been removed but the central shoot gives some idea of the protection afforded the larva, which works close to the twig.

Fig. 4. Tip of lodgepole reproduction after two years' attack by Cacoecia fumiferana var lambertiana(?). Most of dead needles removed by handling.

Fig. 5. Top of small lodgepole after three years of attack by Cacoecia fumiferana var. lambertiana(?). Note decreasing length of annual growth.

Fig. 6. Lodgepole leader after three years' attack by Cacoecia fumiferana var lambertiana(?). Original leader, killed by budworm, replaced by lateral.

Fig. 7. Fall River, Targhee N.F., Aug. 25, 1929. Tree defoliated 1927-8-9 and perhaps somewhat in 1926. Leaders dead. Buds undamaged otherwise.

Fig. 8. Fall River, Targhee N.F., Aug. 25, 1929. Second growth 25 years (?). Defoliated 1927-8-9 -- probably slightly in 1926. Some overtopped trees dead. All leaders dead and most of "shoots" in top 2-3 feet.

Fig. 9. Grand fir after one year's attack by spruce budworm. Attack not severe enough to involve old foliage.

Fig. 10. Grand fir fed on by spruce budworm in 1928 but not in 1929. This is evidence that the epidemic (Coeur d' Alene N.F.) is two years old.

Fig. 11. Douglas fir after two years' feeding by the spruce budworm.

Fig. 12. Hemlock fed on by spruce budworm. No apparent discrimination between old and new growth.

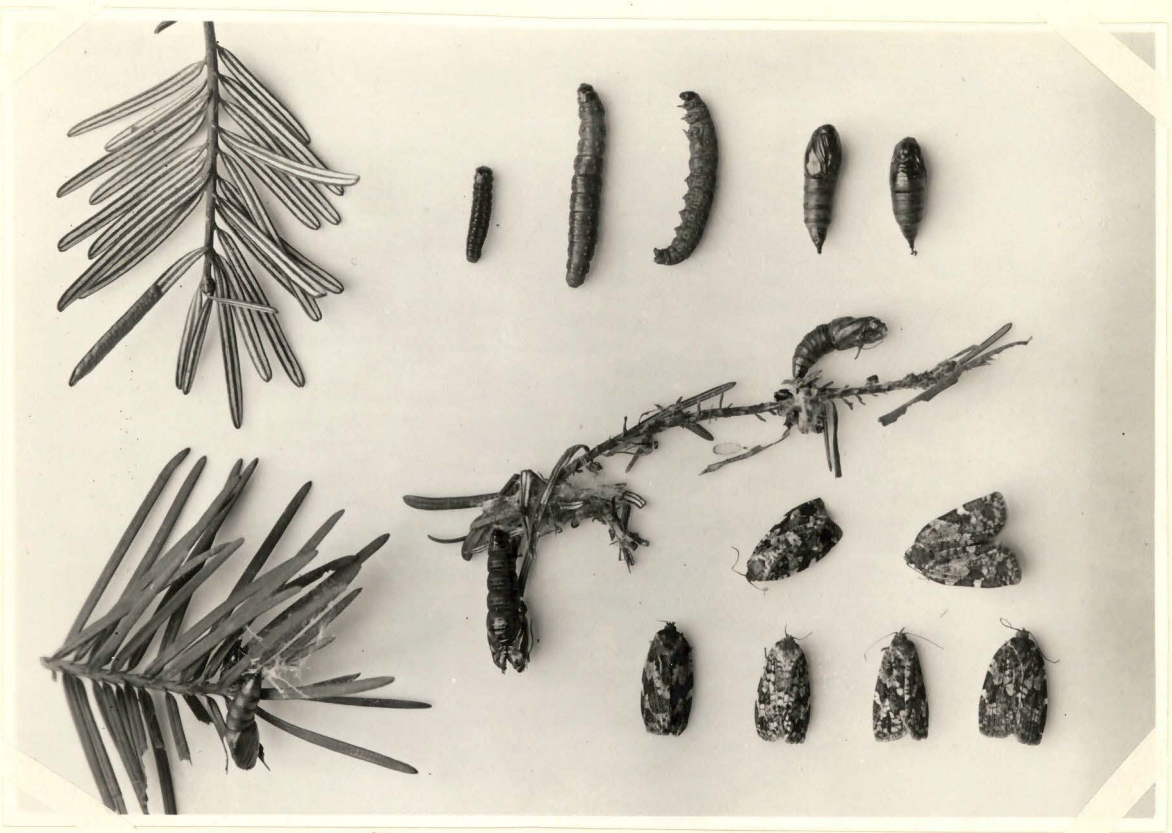
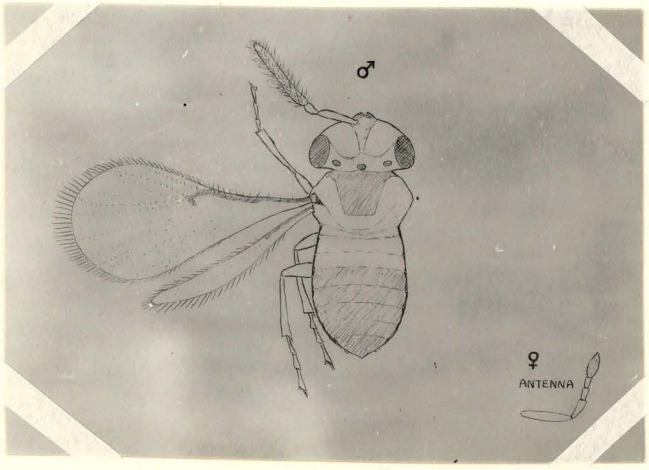


Fig. 13. Stages of the spruce budworm on grand fir: Eggs, larvae, pupae, and adults.



Greatly enlarged

Fig. 14. Trichogramma minuta Riley. An important egg parasite of the budworm at Bechler River.